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Independent Research Project

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SIMULATION OF LIVER WITH THE RESULTS OF ELECTROLYSIS

ABSTRACT

The liver is a critical organ of an organism in charge of a plethora of critical tasks such as the cleansing of blood from toxins, and drugs, the filtering and processing of metabolic products, its contribution to digestion, and the enrichment of blood with nutrients. Electrolysis is a process by which electric current is passed through a substance to change its chemical composition. In this research paper, I suggest an analogy between the functions of the liver with the results of electrolysis. In this direction, I conducted an electrolysis experiment, where a high electrolyte concentration solution was used to simulate the function of a healthy liver and a low electrolyte concentration solution for the function of an unhealthy liver. The electrical power attained by the high concentration solution was much greater than the low concentration solution and increased with increasing current. This is like the behavior of a healthy liver which can operate for longer time intervals with better performance supporting the organism better in its functions. In this sense, vitamins are also produced in the liver which help the body function and in electrolysis we can improve the appearance and behavior of a metal with electroplating. The mass loss of the graphite

electrode for the high concentration solution was much greater than the one for the low concentration solution, meaning that the high concentration solution resulted in higher rejection of graphite. This resembles the operation of a healthy liver that also rejects more harmful substances in an organism compared to an unhealthy liver that rejects less harmful substances and its function is below normal. In conclusion, the healthier the liver, the better the body functions and correspondingly in electrolysis, the better electrolyte solution we use, the faster the electrolysis function.

LIVER

The liver is a multifunctional organ of the human organism positioned in the upper right part of the abdominal cavity. It is immediately inferior to the thoracic cavity, yet largely protected by the rib cage. It is superior to the stomach, right kidney, and intestines.

Structure of the liver

The liver has two large sections, called the right and the left lobes. Both lobes are divided into 8 segments, each of which is subdivided into thousand small lobules. The lobules drain bile to adjacent small ducts which then merge into larger ducts to ultimately form the common hepatic duct. The common hepatic duct carries bile (produced by the hepatic cells) to the gallbladder for storage and release upon demand in the first part of the small intestine (the duodenum).

The blood vessels associated with the liver are the hepatic artery and the portal vein. These blood vessels subdivide into small capillaries known as liver sinusoids, which then lead to lobules.

The main parts that make up the liver are:

1. *Peritoneum*, the smooth ligamentous covering that attaches the liver to the anterior and posterior abdomen, and surrounding organs.
2. *Lobes*, the liver's two major anatomical divisions.
3. *Falciform Ligament*: a thin, fibrous, anterior structure that divides the two lobes of the liver and attaches it to the abdomen.

4. *Lobules*, the liver's microscopic functional units.
5. *Common Hepatic Duct,* the tube through which bile flows from the liver to the gallbladder. The right and left hepatic ducts merge out of the liver to form it.
6. *Glisson's Capsule*, a connective tissue covering that surrounds the liver and encloses the ducts and blood vessels.
7. *Hepatic Artery*, the blood vessel that brings oxygen-rich blood from the aorta to the liver via the celiac trunk.
8. *Hepatic Portal Vein*, the vessel that carries blood rich in digested nutrients from the entire gastrointestinal tract and also from the spleen and pancreas. [1] [2]

Functions of the liver

The liver's main job can be seen as a factory processing food and biochemical substances that come from the digestive tract, circulate in the blood, and whose products are released back into the blood and the digestive system. Being so central to metabolism, it belongs to the digestive system. More than 500 vital functions are performed by the liver.

[1] Johns Hopkins Medicine (2019). *Liver: Anatomy and Functions*. [online] Johns Hopkins Medicine. Available at: https://www.hopkinsmedicine.org/health/conditions-and-diseases/liver-anatomy-and-functions [Accessed 19 Oct. 2022].

[2] Columbia Surgery (2019). *The Liver and its Functions | Columbia University Department of Surgery*. [online] Columbiasurgery.org. Available at: https://columbiasurgery.org/liver/liver-and-its-functions [Accessed 19 Oct. 2022].

Some of these functions include the following:

- *Production of bile*, which helps in the breakdown of lipids in the small intestine and the removal of waste products, such as bilirubin.
- *Synthesis of blood plasma proteins*, such as albumin and clotting factors. The latter are vital for the regulation of blood clotting.
- *Detoxification of blood* from various metabolites, toxins, and drugs into non-toxic or less toxic substances (e.g. conversion of ammonia to urea).
- *Excretion of bilirubin, cholesterol, hormones, and drugs*.
- *Metabolism of fats, proteins, and carbohydrates.*
- *Enzyme activation.*
- *Storage of nutrients* including blood glucose, vitamins A, D, E, K, and B12, and minerals such as iron and copper.
- *Production of cholesterol and blood lipid-transport proteins*.
- *Regulation of levels of glucose and amino acids in the blood*. Excess blood glucose is converted into glycogen for storage. Amino acids can be either used to make new proteins or converted into other energy-rich nutrients.
- *Recycling of red blood cells and their components* (e.g. bilirubin, iron).
- *Contribution to the organism's immunity* by synthesis of immune factors to detect pathogens in the bloodstream and deactivate them. [3] [4]

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[3] Johns Hopkins Medicine (2019). *Liver: Anatomy and Functions*. [online] Johns Hopkins Medicine. Available at: https://www.hopkinsmedicine.org/health/conditions-and-diseases/liver-anatomy-and-functions [Accessed 19 Oct. 2022].

[4] Columbia Surgery (2019). *The Liver and its Functions | Columbia University Department of Surgery*. [online] Columbiasurgery.org. Available at: https://columbiasurgery.org/liver/liver-and-its-functions [Accessed 19 Oct. 2022].

ELECTROLYSIS

Definition of electrolysis

Electrolysis is a common industrial/metallurgical process where a non-spontaneous reaction is forced to occur by passing electric current.

Electrolytes

Electrolytes are substances that, when dissolved in water, produce ions. This is because the current passing through them is carried by ions and not by electrons. It is obvious that a solid substance cannot serve as an electrolyte because its ions are strongly bounded, so they cannot move.

Galvanic cell

A voltaic cell is a type of electrochemical cell that produces electrical energy by using chemical processes within its internal circuitry.

The following are the important components of a voltaic cell:

- The *anode* is an electrode where *oxidation* (loss of electrons) takes place. Therefore, the anode is *negatively* charged.
- The *cathode* is an electrode that undergoes *reduction* (gains electrons), so ends up *positively* charged.
    - The anode and the cathode are also called "*half cells*" and are located in *different containers*.
- The two containers are connected through a "*salt bridge*". Its purpose is to prevent the buildup of charge within the two solutions that the half-cells are placed in.

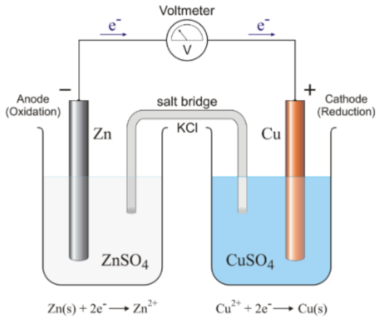

Figure 1: A schematic representation of a voltaic cell[5]

Assume the voltaic cell shown in Figure 1, where the anode is zinc and the cathode is copper.

The *half reaction* in anode is

$$Zn \rightarrow Zn^{2+} + 2e^{-1}$$

and the *half reaction* in cathode is

$$Cu^{2+} + 2e^{-1} \rightarrow Cu$$

This shows that the *oxidation number* of zinc *increases* from zero (its natural state), to +2, while copper's *oxidation number reduces* to zero.

The zinc electrode gives away electrons that travel form the anode to cathode. Therefore, the anode becomes negatively charged and the cathode positively charged. As electrons flow, a potential difference is created, and the voltmeter gives a reading.

As zinc atoms lose two electrons they turn into ions, leave the electrodes and dissolve into the solution. On the other side, there are already copper ions into the solution. They are attracted to the cathode by acquiring the incoming electrons and deposit themselves on the surface of the cathode. Over time, the *cathode grows bigger* because it gains mass whereas *the*

[5] Bramer, B. (2021). *Voltaic Cells & Galvanic Cells | Electrochemical Cells*. [online] ChemTalk. Available at: https://chemistrytalk.org/electrochemical-cells/ [Accessed 17 Oct. 2022].

anode gets smaller because is losing mass. So, the *anode gradually disappears*.

As it can be easily understood that in a galvanic cell, electrical energy is created by the spontaneous transformation of the energy released by the so-called *redox* (reduction – oxidation) reaction.

The electrolytic cell

An electrolytic cell uses electric current to drive a thermodynamically ***unfavorable*** reaction. A simple way of explaining it is like charging up a rechargeable battery from a wall outlet.

Electrolysis takes place in a special device, known as electrolytic cell, which typically consists of the following components:

- A container containing an electrolyte in a molten state or in an aqueous solution
- A source of electric current (power supply)
- Two inert electrodes connected to the source

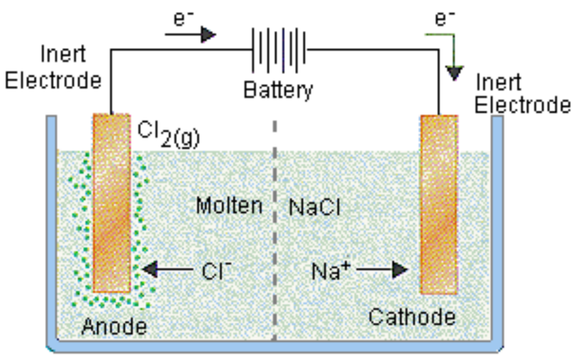

Figure 2: A schematic representation of an electrolytic cell[6]

[6] Admin (2022). *Electrolytic Cell Questions - Practice Questions of Electrolytic Cell with Answer & Explanations*. [online] BYJUS. Available at: https://byjus.com/chemistry/electrolytic-cell-questions/ [Accessed 19 Oct. 2022].

Figure 2 presents a schematic diagram of an electrolytic cell for the electrolysis of molten sodium chloride to form liquid sodium and chlorine gas.

Let's focus on the ***right-hand electrode***:

As it can be seen in Figure 2, the negative terminal of the power source is where the electrons come from. So, the electrons flow from the wire to the inert electrode. *Inert* means that the electrodes don't participate in this reaction. Graphite or platinum electrodes are commonly used.

On this electrode the electrons *reduce* the liquid sodium ions into liquid sodium (please note that *l* stands for *liquid*, *g* stands for *gas)*:

$$2Na_l^{+2} + 2e^{-1} \rightarrow 2Na_l$$

Consequently, liquid sodium will be formed on the electrode. Since *reduction* takes place on the ***right-hand electrode***, this is now the ***cathode***.

Let's focus on the ***left-hand electrode***:

At this electrode oxidation is taking place since ***liquid*** chloride anions are turning into chlorine ***gas***. Therefore, bubbles of chlorine gas can be observed at this electrode.

$$2Cl_l^{-} \rightarrow 2Cl_g + 2e^{-1}$$

Also, as liquid chloride anions are *oxidized* there is loss of electrons. So, the electrons flow for the electrode, through the interconnecting wire towards the positive terminal of the power supply. Since *oxidation* is occurring at the inert electrode on the left, this electrode is the *anode*.

The main differences between an electrolytic cell (E.C) and a voltaic cell (V.C) are that an E.C:

- transforms electrical energy to chemical energy
- the *redox* reaction isn't spontaneous
- the electrodes are located in the same container
- the negatively charged electrode is the cathode whereas the positively charged one is the anode.
- electrons aren't produced by a chemical reaction but through an external power supply.

Function of electrolytic elements

Faraday Laws – Calculations

The experimental study of the phenomenon of electrolysis led Faraday (1833) to determine the relationships between the masses released (electrolysis products) and the amount of electricity passing through the electrolytic conductor. These quantitative relations are described by the following two laws:

First law[7]. *"The mass of an element liberated during electrolysis is proportional to the amount of electricity passing through the electrolyte"*, i.e.

$Mass\ (\boldsymbol{M}) \propto Current\ (\boldsymbol{I}) \times time(\boldsymbol{t})$

Second law. *"The masses of various elements liberated by the passage of a constant quantity of electricity through different electrolytes are proportional*

[7] Wudy, F., Stock, C. and Gores, H.J. (2009). MEASUREMENT METHODS | Electrochemical: Quartz Microbalance, Editor(s): Jürgen Garche, Encyclopedia of Electrochemical Power Sources, Elsevier, 2009. *www.sciencedirect.com*, [online] pp.660–672. doi:10.1016/B978-044452745-5.00079-4.

to the chemical equivalents of the ions undergoing the reaction", i.e. $Mass\ (\boldsymbol{M})\ \propto \frac{the\ mass\ of\ 1\ mole\ of\ the\ ion}{the\ charge\ on\ that\ ion}$ (***E***)

The combination of the two laws gives the following relationship: $M\ \propto ItE$ or $M = (\boldsymbol{Faraday}\ constant)ItE$.

For 1 mole of an ion having charge +1, the Faraday constant is found to be 1 Faraday, for 1 mole of an ion having charge +2 is 2 Faradays, etc. This allows merging Faraday's constant and ***E***, in a single constant called the *electrochemical equivalent* ***z***, $Mass\ (\boldsymbol{M}) = \mathbf{z} \times Current\ (\boldsymbol{I}) \times time(\boldsymbol{t})$ where z is the ***mass liberated by 1 ampere in 1 second.***

In simple steps:

1. Record the time of the process and convert it to seconds
2. Calculate the charge as the current ***I*** through the circuit divided by the time above
3. Use the conversion that 1 mole of electron = 96.485 C (***Faraday's constant***).

Use of Electrolysis

Electrolysis is used

- to remove rust from metals
- to place a thin layer of one metal on the top of the other, a process called electroplating.
- to purify metals such as aluminum, lithium, potassium, magnesium, and sodium.
- in the production of chlorine, sodium chloride, sodium hydroxide, and potassium chloride.
- in the energy industry to produce hydrogen as a fuel (fuel cells).

- in the aerospace industry, to create oxygen for spacecraft.
- to isolate oxygen for submarines.
- to electrolyte metal plating on a surface and for electrochemical treatment to scratch, clean a surface or remove rust from it, in addition to chemical synthesis and cleaning.[8] [9]

Simulation of liver with the results of electrolysis (metal cleaning and plating)

The liver filters, cleanses the blood and enriches it with various ingredients. So, we can simulate its operation with the results of an electrolysis.

The next two procedures can simulate liver function.

1) The removal of rust from a metal object so that we return it to its original state. This procedure corresponds to the removal of harmful substances and toxins from the blood.

2) Plating with the help of electrolysis which can simulate the storage of substances such as proteins, vitamins, glycogen.

Removing Rust

Electrolysis should be done in an area with plenty of ventilation (or outdoors), since it releases hydrogen and oxygen gases, which could be flammable if they build up. The apparatus required is the following:

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[8] The Editors of Encyclopaedia Britannica (2019). Johann Wilhelm Ritter | German physicist | Britannica. In: *Encyclopædia Britannica*. [online] Available at: https://www.britannica.com/biography/Johann-Wilhelm-Ritter [Accessed 19 Oct. 2022].

[9] BYJUS. (n.d.). *Electrolysis - Definition, Process, Applications, Electrolysis of Water*. [online] Available at: https://byjus.com/jee/electrolysis/ [Accessed 19 Oct. 2022].

- A plastic bucket or a plastic container depending on the size of the objects.
- A car battery charger, of 6, 9 or 12 volts
- As electrolyte, use washing soda dissolved in water.
- Warm water, for faster results
- The cathode will be the tool/material to remove the dust from.
- The anode can be a scrap piece of an iron bar.
- Plastic Clamps to hold firmly the anode and the cathode.
- Make sure that the anode and cathode are placed well apart and that they don't touch each other.
- Finally connect the positive terminal of the charger on the metal bar and the negative on the tool/material. This is because electrons flow from the low potential to the higher one and this current flow helps to remove the rust.
- Switch on the battery charger and wait a few hours or until the next day, depending on amount of rust present. After this time most (if not all) of the rust should have been removed from the tool.
- Dispose the remaining of the solution appropriately.

Electroplating

Nickel electroplating is amongst the most common procedures because it is resistant to corrosion and offers hardness and ductility. It improves also the external look of the product.

The jewelry business makes extensive use of this method. The process of plating involves applying a thin layer of metal to the surface of another metallic object. The added metal covers the object's less desirable characteristics. For instance, gilding a bronze object not only gives it a golden sheen but also protects it from surface oxidation (rust) because gold itself does not oxidize.

It stands to reason that the price would skyrocket if the item were made of solid gold. Typically, the thickness of the metal layer that needs to be placed is on the order of 1 micron (1 millimeter of a millimeter).

Gilding, silver plating, platinum plating, impregnation, etc. are all examples of popular plating techniques. These are noble metals as well as the substances important for the body that are stored in the liver.

Electroplating can be performed using an electrolytic cell, as the one described in Figure 2. Let's assume that there is a steel pendant that needs to be protected from corrosion. The cathode will be the steel object (steel electrode). The anode is going to be a nickel bar (nickel electrode). For electrolyte an aqueous solution of nickel sulfate ($NiSO_4$) can be used. As it was thoroughly described previously, electrons move from the cathode and reduction takes place through the following half reaction (please note that *l* stands for *liquid*, *s* stands for *solid)*:

$$Ni_l^{+2} + 2e^{-1} \rightarrow Ni_s$$

where nickel in liquid form takes in two electrons and deposits itself as solid onto the cathode. So, a thin layer of nickel is placed on the steel pendant.

On the anode and oxidation takes place through the following half reaction:

$$Ni_s \rightarrow Ni_l^{+2} + 2e^{-1}$$

The two electrons released move towards the positive end of the power supply.

A similar electroplating takes place for *silvering* as well. In this case the cathode will be the object/tool for plating, the anode a plate of *pure silver* and as electrolyte an *$AgNO_3$ aqueous* solution.

The experiment

The aim of this practical investigation is to simulate the operation of a healthy liver under the assumption that is similar to the behavior of a solution with a high electrolyte concentration. The experiment was conducted at school's laboratory. The *independent variable* is *concentration of electrolyte* (sodium carbonate) in the solution and *dependent* the *intensity of the electric current I (A)*. The electrodes were made from graphite and copper.

Apparatus:

- 0-30V variable voltage source, set to 9 volts
- Two multimeters (one for voltage and one for current measurement). The voltmeter is connected in parallel and the ammeter in series.
- Digital timer,
- Interconnecting Cables.
- Deionized water and sodium bicarbonate were used for the solution.

- Electronic balance (to record the mass of the graphite electrode).

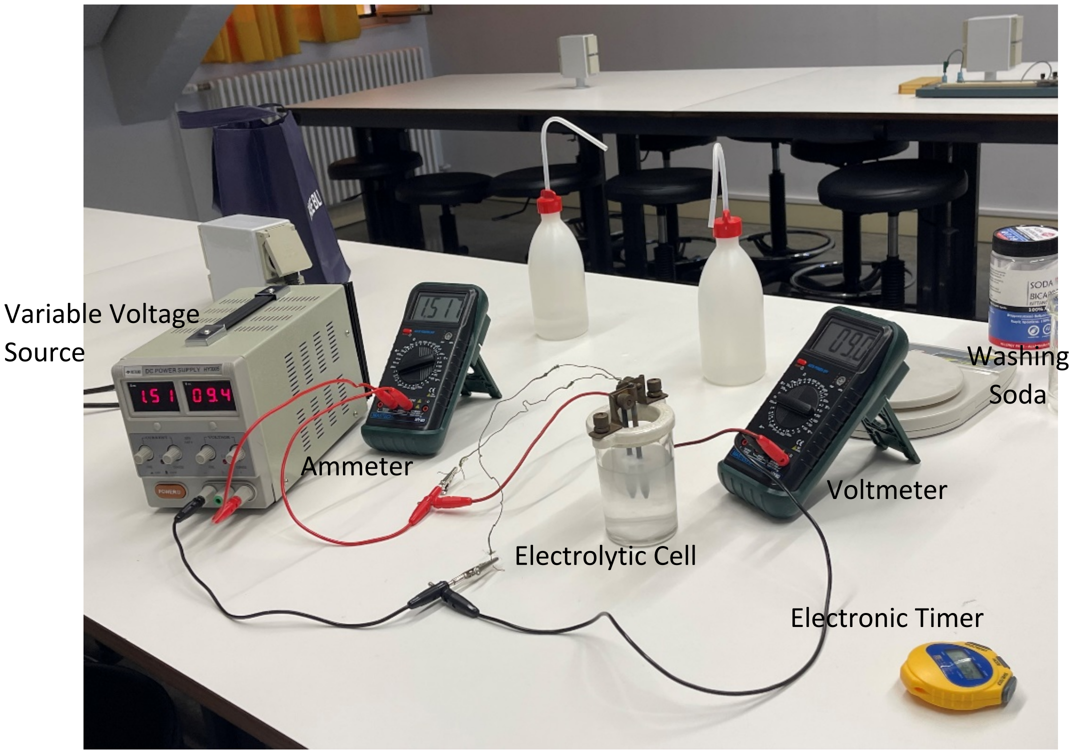


Figure 3: Photograph of the experimental setup

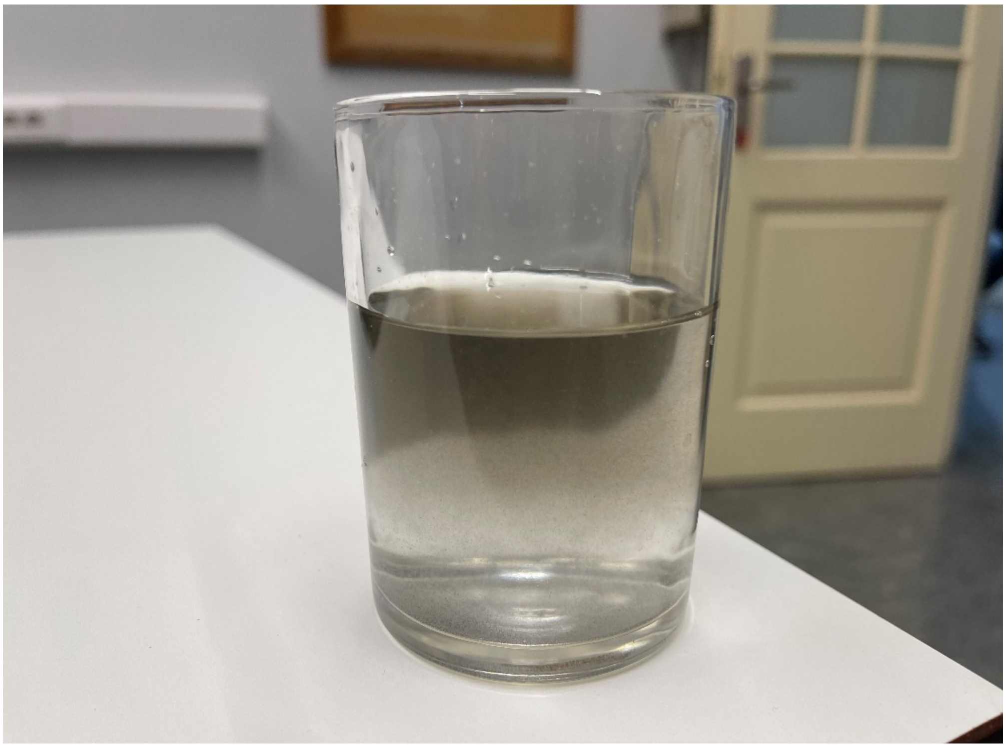


Figure 4: Photograph of the ***high concentration*** solution after the experiment

Procedure:

- Use the electronic balance to record the mass of the graphite electrode.
- Clean the bucket or the plastic container.
- Prepare the solution. The first solution is of high concentration, i.e. 200 *ml* of Deionized Water and 21 gr of sodium bicarbonate. The second is of low concentration with 200 *ml* of Deionized Water and 10 gr of sodium bicarbonate.
- Set the apparatus as shown in Figure 3.
- Make sure that the graphite is the anode and the copper the anode
- Switch on the voltage source and at the same time start the digital timer.
- Record the time from the digital timer and the value of the current from the ammeter at the specified time intervals. As shown in Tables 1 and 2.
- At the end of the experiment record the remaining mass of the graphite electrode.
- Make sure that the voltage supplied remains constant at 9V throughout the whole experiment.
- Evaluate the Power P (W) by multiplying the value of the electric current I (A) and the voltage V (V) supplied by the source.
- Plot a graph of Electric Current I (A) Vs Time (s).

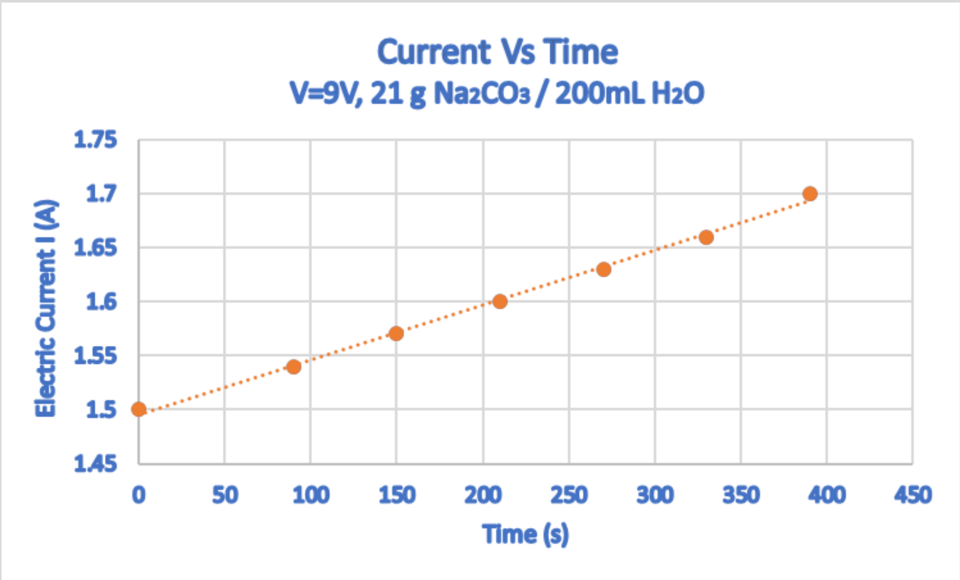
Results:

V=9V	$21\ g\ Na_2CO_3\ /\ 200mL\ H_2O$	
t (s)	I (A)	P (W) = V*I
0	1.5	13.5
90	1.54	13.86
150	1.57	14.13
210	1.6	14.4
270	1.63	14.67
330	1.66	14.94
390	1.7	15.3

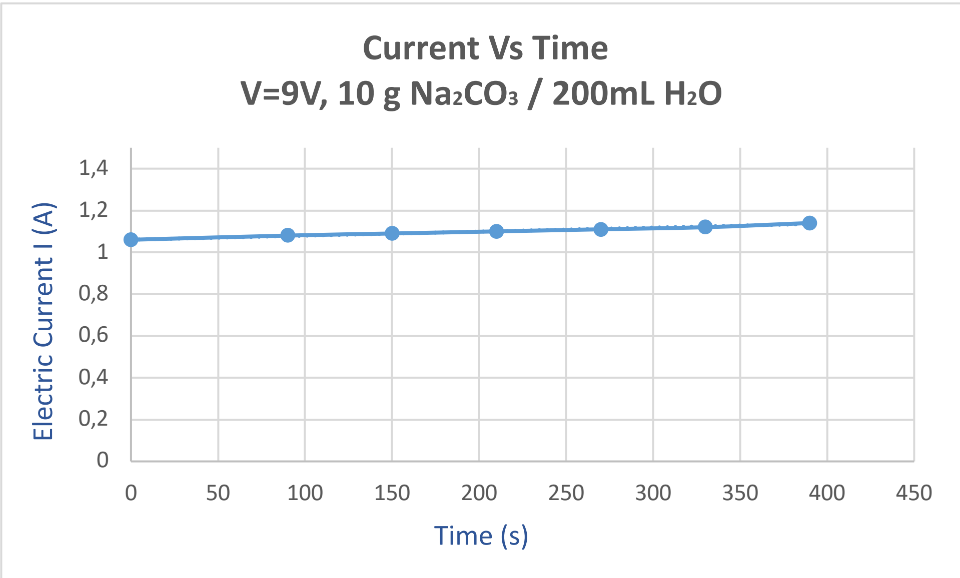
Table 1: Experimental data for the high concentration solution

V=9V	$10\ g\ Na_2CO_3\ /\ 200mL\ H_2O$	
t (s)	I (A)	P (W) = V*I
0	1.06	9.54
90	1.08	9.72
150	1.09	9.81
210	1.1	9.9
270	1.11	9.99
330	1.12	10.08
390	1.14	10.26

Table 2: Experimental data for the low concentration solution



Graph 1: Electric Current Vs Time for the ***high concentration*** solution



Graph 2: Electric Current Vs Time for the ***low concentration*** solution

Discussion

- The solution with high concertation was used in order to simulate the behavior of a healthy liver, while the one with low concentration, the behavior of an unhealthy one.
- From Tables 1 and 2 it is noted that the power attained the high concentration solution was much greater and increased with increasing current. This is like the behavior of a healthy liver which can operate for longer time intervals with better performance.[10]
- The mass loss of the graphite electrode for the high concentration solution was much greater than the one for the second solution, meaning that the high concentration solution resulted to higher rejection of graphite. This resembles the operation of a healthy liver that also rejects most of the harmful substances for the organism. The opposite is observed for the lower concentration solution. Indeed, an unhealthy liver rejects less harmful substances as its function is below normal/nominal.[11]

  Additionally, Faradays Law is verified, since the greater the current the greater the mass loss of the anode electrode.
- More variables could have been considered in this experiment. For example, use of
  - different electrodes,
  - different electrolytes

[10] Arul, T.M. (2020). *liver-health*. [online] www.medstarhealth.org. Available at: https://www.medstarhealth.org/blog/liver-health [Accessed 19 Oct. 2022].

[11] Cleveland Clinic (2017). *Liver Failure | Cleveland Clinic*. [online] Cleveland Clinic. Available at: https://my.clevelandclinic.org/health/diseases/17819-liver-failure [Accessed 19 Oct. 2022].

    - more concentrations
    - different value of voltage supplied (greater or lower than 9 V)
- Additionally, the effect of solution temperature in the whole experiment.

It should also be noted that two basic factors to improve electrolysis are:

• The quality of the electrolyte

• Energy supply

Accordingly, two factors that improve the operation of a liver are:

• The quality of the blood

• Energy supply

Conclusion

- Electrolysis is a complex mechanism consisting of two electrodes, one positive and one negative, just as the liver consists of two large parts, the left and right lobes.
- Vitamins are also produced in the liver which help the body function and in electrolysis we can improve the appearance and behavior of a metal with electroplating.
- The healthier the liver, the better the body functions and correspondingly in electrolysis, the better electrolyte solution we use, the faster the electrolysis function.
- A healthy body has more energy and therefore better functioning. By supplying more electrical energy to the electrolysis, the operation of the voltmeter is accelerated.

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